ILLUMINATION SYSTEM WITH RASTER ELEMENTS OF DIFFERENT SIZES

CROSS REFERENCE TO RELATED APPLICATIONS

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The present application is claiming priority of German Patent Application Serial No. 101 00 265.3, which was filed on January 8, 2001.

BACKGROUND OF THE INVENTION

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1. Field of the Invention

The present invention concerns an illumination system, particularly one that is used for lithography, for example, VUV and EUV-lithography with wavelengths of less
15 than or equal to 193 nm, which illuminates a field, wherein the illumination system comprises at least one light source as well as optical elements, which are divided into raster elements.

2. Description of the Prior Art

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In order to be able to even further reduce the structural widths for electronic components, particularly in the submicron range, it is necessary to reduce the wavelength of the light utilized for microlithography.

25 For example, lithography with soft x-rays is conceivable at wavelengths of smaller than 193 nm. A double-facetted illumination system for such wavelengths has become known, for example, from DE 199 03 807. The disclosure content of DE 199 03 807 is incorporated herein by reference.

30 In the case of the illumination system known from DE 199 03 807, first raster elements, which are also denoted field raster elements, are illuminated via collecting optics. When arranged in reflection, illumination is produced at a specific angle of incidence. Therefore, the illuminated field on the field raster elements is preferably

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elliptical. The field raster elements are configured rectangularly, however, corresponding to the desired field in the object plane, which coincides with the reticle plane.

5   Each field raster element is imaged in a field in an object plane, in which the reticle is positioned. Since each field raster element contributes to the uniformity of the illuminated field, field raster elements that are only partially illuminated adversely affect the uniformity in the object plane. Thus, only completely illuminated field raster elements should be used.

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In systems, such as are known from DE 199 03 807, the first raster elements or facets have a typical aspect ratio of approximately 1:16. In such systems, field raster elements cover only about 80% of the area illuminated by the light source, i.e. approximately 20% of the power is lost. Since the number of field raster elements is

15   limited by the optical elements arranged in the light path from the light source to the reticle plane behind the optical element with first raster elements and for reasons of geometry and capability of construction, a better efficiency for an illumination system as is known from DE 199 03 807 cannot be achieved simply by increasing the number of field raster elements.

20   SUMMARY OF THE INVENTION

An object of the invention is thus to provide a imaging system that overcomes the disadvantages of the prior art, and particularly has a high utilization of the irradiated

25   light power.

The object is solved according to the present invention by an illumination system, particularly for lithography with wavelengths of ≤193 nm, comprising a first optical element, which is divided into first raster elements and lies in a first plane, whereby

30   the plane defines an x-direction and a y-direction, whereby the images of the first raster elements superimpose in an object plane of the illumination system and the first raster elements each have an x-direction and a y-direction with an aspect ratio,

characterized in that at least two raster elements each have an aspect ratio of different magnitudes.

According to the invention, in order to minimize the light losses, the first raster elements, which are also denoted field raster elements, have different shapes. For example, they can be of different sizes or the aspect ratio of the individual field raster elements may vary over the field raster element mirror, so that a better covering of the illuminated area in the plane where the field raster elements are situated by the plurality of field raster elements and thus a higher efficiency of the illumination system is achieved.

In order to compensate for the different sizes or aspect ratios of the first raster elements or field raster elements, the second raster elements or pupil raster elements are anamorphic. The anamorphism or astigmatic action of each pupil raster element is adapted for this purpose to the aspect ratio of each field raster element.

The essential characteristic of the invention is thus that pupil raster elements of different anamorphotic effect combined with field raster elements of different aspect ratios lead to a higher energy utilization of the light source by the illumination system. This is achieved in that the second raster elements have different anamorphotic effects, so that the aspect ratio of the images of the first raster elements in the object plane of the illumination system, in which, for example, a reticle is positioned, essentially corresponds to the field aspect ratio, independently of the aspect ratio of the first raster elements. The field raster elements may have, but need not have, an anamorphotic effect.

An anamorphotic effect can be realized in the simplest case by a toric surface shape, i.e., the radii of curvature of a mirror in the x- and y-directions differ at the vertex of the mirror in x- and y-directions, i.e., R_y is not equal to R_x.

Other advantageous embodiments of the invention are the subject of the subclaims.

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BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be described below, for example, on the basis of the drawings.

5 Here:

Figure 1 shows a field raster element plate with many identical field raster elements, which are either isotropic or anamorphotic.

10 Figure 2 shows the configuration of a field raster element plate according to the invention with field raster elements with different aspect ratios. For better arrangement, all the field raster elements of one row are each of the same height; only the width is changed.

15 Figure 3 shows a schematic diagram for the derivation of formulas for isotropic field raster elements and pupil raster elements.

Figure 4 shows a schematic diagram for the derivation of the linear magnification for anamorphotic pupil raster elements, whereby the field raster elements are configured
20 as field raster elements with large convergence.

Figure 5 shows a schematic diagram for the derivation of the linear magnification for anamorphotic pupil raster elements, whereby the field raster elements are configured as field raster elements with weak convergence.

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Figure 6 shows a schematic diagram of an illumination system.

Figure 7 shows a schematic diagram of a projection exposure system.

30 DESCRIPTION OF THE INVENTION

Figure 1 shows a conventional configuration of a field raster element plate 1 with field raster elements 3 of identical size, as have been made known from DE 199 03 807.

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The field raster elements 3 have a typical aspect ratio of approximately 1:16. Approximately 200 field raster elements 3 are arranged on a slightly elliptical illuminated surface. Approximately 80% of the illuminated surface is covered by field raster elements, i.e., approximately 20% of the power is lost.

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In order to minimize this loss, according to the invention, the field raster elements, as shown in Figure 2, have different shapes. In this way, field raster elements 3 can be configured of different dimensions, and also the aspect ratio of the individual field raster elements 3 over a plate or mirror, i.e., field raster element plate 1, may vary so

10 that a better covering of the illuminated surface by field raster elements and thus a higher efficiency result.

A field raster element plate 1 configured in this way is shown in Figure 2; for this purpose, field raster elements 3 of the field raster element plate 1 shown in Figure 1

15 were reconfigured so that a better covering results. The efficiency can be increased to more than 95%. The number of field raster elements was slightly increased at the same time, which is in fact not necessary, but is helpful. The field raster elements are arranged in rows 5.

20 For a better arrangement, all field raster elements of a row 5 in the embodiment according to Figure 2 are of the same height; only the width is varied. The x-direction runs upward to the top, and the y-direction runs to the right.

The following derivation based on Figure 3 gives the different refractive powers by a

25 calculation according to geometric-optical formulas, as a function of the different widths of the field raster elements.

The case of a light channel between a field raster element 3 and a pupil raster element 7 will be considered first, wherein the field raster element 3 is isotropic, as is also

30 pupil raster element 7. For this case of an isotropic field raster element 3 and exact Köhler illumination, the size of field raster element 3 with aperture NA_1 behind pupil raster element 7, respectively, for the double-facetted system is coupled via:

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(1)

$$NA_I = \frac{y_o}{Z}$$

wherein

y_0: height of the field raster element (half the diameter in the y-direction)

Z: distance between field raster element and pupil raster element

Further, a light-source image 9, which field raster element 3 produces, lies in plane of the pupil raster element 7, i.e., the point of intersection of the aperture beam and the optical axis HA lies in the plane of pupil raster element 7. For the refractive power of the field raster element in this case, it follows that

(2)

$$\frac{1}{f_y^{fw}} = \frac{1}{Z} + \frac{1}{D}$$

wherein

D: distance between light source and field raster elements

f_y^{fw}: focal distance of the field raster elements in the y-direction.

If one assumes values that are typical for an EUV illumination system:

$D = 1200$ mm for the distance D between the light source and the field raster elements

$Z = 900$ mm for the distance between the field and the pupil raster elements

$\beta = -3.5$:

typical lateral magnification for the pupil raster element

$S_1 = 3150$ mm :

distance between the vertex of the pupil raster element and the image of the field
raster element $S_1 = -Z \cdot \beta$

$2x_0 \times 2y_0 = 2.8$ mm x 46 mm:

5   size of the field raster element,

then the following design values result for isotropic field raster elements or pupil
raster elements:

10   focal distance of the field raster element:
$f^{fw} = 514.286$ mm

focal distance of the pupil raster element:
$f^{pw} = 700$ mm

15   radius of curvature of the field raster element in a reflective design:
$R^{fw} = -2\ f^{fw} = -1028.571$ mm

radius of curvature of the pupil raster element in a reflective design:
20    $R^{pw} = -1400$ mm.

If all field raster elements 3 are made equal in the x-direction, as shown in Figure 2,
and the aspect ratios of field raster elements 3 are changed only by changing the width
in y, then Equation (1) can be applied in the x-direction. Then the values of the
25   previous section apply for the x-direction. For the y-direction, it is necessary to
change the refractive power of the pupil raster elements.

If the refractive power of pupil raster element 7 is changed, then the magnification is
also changed. Therefore, the distance between the vertex of the pupil raster elements
30   and the image of the field raster elements S_1 is also changed to S'_1, while the distance
between field raster elements and pupil raster elements on the object side remains the
same: $S_0 = -Z$.

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The image plane with distance S_1 to the pupil raster elements is imaged by the imaging optics of the illumination system in the object plane to be illuminated. If the image of a field raster element is formed in another plane than the image plane with distance S_1 to the vertex of the pupil raster elements, the image in the object plane that

5   is to be illuminated, which coincides with the reticle plane, is blurred. This must be taken into account in the design of the pupil raster element with a specific lateral magnification, in order to prevent unnecessary large light losses. As shown in Figure 4, the surface to be illuminated in the plane with distance S_1 conjugated to the object plane is thus broadened by

10   (3)

$$\Delta y' = (S_1 - S'_1) \cdot \tan(\arcsin(p_1)) = dz \cdot \tan(\arcsin(p_1)) \approx dz \cdot p_1$$

wherein

$\Delta y'$: half broadening of the length to be illuminated in the plane with distance S_1

15   $dz = S_1 - S'_1$: distance between the image planes

p_1 : optical direction cosine of the maximum aperture beam for the imaging beam path with a point-like light source.

In addition, the illumination is broadened in case of a source with a finite size by the

20   aperture of the secondary light source in the object plane. Usually, this aperture and the additional broadening that it produces, however, are negligibly small. This small amount of broadening by the finite source size will be disregarded in the following derivation.

25   (4)

$$\beta y_0 \approx \beta' y'_0 + dz' \cdot p_1$$

β: lateral magnificaton of the imaging by the conventional pupil raster element with normal field raster element

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β': lateral magnification of the anamorphotic pupil raster element in the y-direction

y_0: field raster element height for the conventional design

y_0': field raster element height for the design with modified aspect ratio

5   dz': longitudinal image misalignment in the image plane behind the pupil raster element

p_1: optical direction cosine in the image space of the pupil raster element (y-component); corresponds to the aperture behind the raster element condenser.

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If the well-known imaging equation of the first order is inserted for p_1:

(5)

$$p_I = \frac{1}{f_y} y'_o + \frac{1}{\beta'} p'_o$$

15   wherein

p'_o: optical direction cosine in the object space of the pupil raster element (y-component)

f_y: focal distance of the pupil raster element in the y-direction,

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then after converting and inserting the distances S_1, S_1', S_0 with $\beta' = S'_1/S_0$, $\beta = S_1/S_0$ and $dz = S_1 - S'_1$:

(6)

$$S'_I = \frac{S_I S_o (y'_o - S_o p'_o)}{S_o (y'_o - S_o p'_o) + S_I (y'_o - y_o)}$$

25   p'_o must now still be selected, i.e., the collecting or convergent power of field raster elements 3 must be determined.

For this purpose, one uses generalized Equations (1) and (2) and obtains from

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(7)

$$p_0 = y'_0 \left(\frac{1}{f_y^{fw}} - \frac{1}{D} \right)$$

wherein

y'_0: height of the field raster elements with modified field aspect ratio

f_y^{fw}: focal distance of the field raster elements in the y-direction

D: distance between light source and field raster elements.

If the following parameters are selected, which are taken from the typical design example above, wherein the following is also valid:

$y_0 = 23$ mm:

half the diameter of the "normal" non-anamorphotic field raster elements in the y-direction,

$M = 10$ mm:

diameter of the pupil raster elements,

and if one also selects as the raster element size for the field raster elements with modified aspect ratio:

$y_0' = 26$ mm:

half the diameter of the field raster elements with modified aspect ratio in the y-direction,

then one has three possibilities in principle for realization. Only the focal distances are indicated each time; the corresponding radii of curvature R_x and R_y in the x-direction and y-direction of the anamorphotic mirror are each indicated by $-2f_x$ or $-2f_y$.

In a first embodiment according to Figure 4, field raster elements 3 with larger convergence are utilized. Thus the beam bundle behind field raster element 3 is not vignetted by pupil raster element 7 of finite extent, so that the following must apply (8)

$$p'_0 > \frac{|y'_0| + \frac{M}{2}}{S_0}$$

here $p'_0 > -0.034$. With $p'_0 = -0.033$, the following values are obtained from Equation (6) and Equation (7) for the focal distances:

Focal distance in the y-direction of the field raster element with height of 26 mm:
$f_y^{fw} = 475.61$ mm

Focal distance in the y-direction of the assigned pupil raster element:
$f_y = 429.28$ mm

Focal distance in the x-direction of the field raster element with height of 1.4 mm:
$f_x^{fw} = 514.286$ mm

Focal distance in the x-direction of the assigned pupil raster element:
$f_x^{pw} = 700$ mm.

In a second form of embodiment according to Figure 5, weak convergent field raster elements are used.

Thus the beam bundle behind field raster element 3 is not vignetted by pupil raster element 7 of finite extent, so that the following must now be applied:

(9)

$$p'_0 < \frac{|y'_0| - \frac{M}{2}}{S_0}$$

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here $p'_0 < -0.0233$. With $p'_0 = -0.024$, the following values for the focal distances are obtained from Equation (6) and Equation (7):

Focal distance in the y-direction of the field raster elements with height of 26 mm:

5     $f_y^{fw} = 569.34$ mm.

Focal distance in the y-direction of the assigned pupil raster elements:

$f_y = 1490.32$ mm.

10   Focal distance in the x-direction of the field raster elements with height of 1.4 mm:

$f_x^{fw} = 514.286$ mm.

Focal distance in the x-direction of the assigned pupil raster elements:

$f_x^{pw} = 700$ mm.

15   For manufacturing reasons, it is preferred to curve the field facets 3 isotropic, i.e., spheric, and to have only pupil raster elements 7 with an anamorphotic effect, in order to compensate for the different aspect ratios of the field raster elements. Field raster elements 3 with different aspect ratios may be designed, for example as follows:

20   Focal distance of the field raster element with dimensions of 2.8 mm x 46 mm:

$f_x^{fw} = f_y^{fw} = 475.61$ mm.

Focal distance in the y-direction of the assigned pupil rster element:

25     $f_y = 429.28$ mm

Focal distance in the x-direction of the assigned pupil raster element:

$f_x^{pw} = 700$ mm.

30   For another field raster element with a height $y_0'' = 20$ mm, which is thus narrower and has a smaller aspect ratio, for example, the following results:

Focal distance of the field raster element with dimensions of 2.8 mm x 40 mm:

$f_x^{fw} = f_y^{fw} = 402.68$ mm.

Focal distance in the y-direction of the assigned pupil raster element:
$f_y = 921.72$ mm.

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Focal distance in the x-direction of the assigned pupil honeycomb:
$f_x^{pw} = 700$ mm.

And, of course, for the original field raster element with the height of 23 mm:

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Focal distance of the field raster element:
$f^{fw} = 514.286$ mm.

Focal distance of the pupil raster element:
15    $f^{pw} = 700$ mm.

A schematic diagram of an illumination system, in which the invention can be used, is
shown in Figure 6. The illumination system comprises a light source or an
intermediate image of a light source 100. The light emitted from the light source or
20   the intermediate image of light source 100, of which only three representative rays are
depicted, strikes a first optical element 102 with a plurality of first raster elements, so-
called field raster elements. Optical element 102 is thus also denoted a field raster
element plate or mirror. The dimensions of the field raster elements on the field raster
element plate are selected according to the invention such that a high covering of the
25   area illuminated by the light source results and only a small amount of power from the
light source is lost. The second raster elements, the so-called pupil raster element of a
second optical element 104, have an anamorphotic effect, which compensates for the
different sizes of the field raster elements. The optical elements 106, 108 and 110
arranged in the light path from the light source to a reticle plane after the second
30   optical element 104 essentially serve for the purpose of forming a field in the reticle
plane 114. The reticle in the reticle plane is a reflection mask. The reticle can be
moved in the depicted direction 116 in the EUV projection system designed as a
scanning system.

Exit pupil 112 of the illumination system is illuminated for the most part homogeneously by means of the illumination system shown in Figure 6. Exit pupil 112 coincides with the entrance pupil of an projection objective. Such a projection objective, for example, with six mirrors, is shown in US Patent Application 09/503,640, the disclosure of which is incorporated by reference.

The optical part of a projection exposure system beginning at the position of a physical light source 122 up to an object 124 to be exposed is shown in Figure 7. The same components as in Figure 6 are given the same reference numbers. The system according to Figure 7 comprises the physical light source 122, a collector 120, the illumination system from Fig. 6, a projection objective, for example with six mirrors 128.1, 128.2, 128.3, 128.4, 128.5 and 128.6 according to US Patent Application 09/503,640 as well as object 124 to be exposed.

For the first time an EUV Illumination system, with which the thermal load on the second facetted mirror element can be reduced is provided.